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# Mungbean [*Vigna radiata* (L.) Wilczek] and its potential for crop diversification and sustainable food production in Sub-Saharan Africa: a review

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## Abstract

Mungbean [*Vigna radiata* (L.) Wilczek] is an important tropical legume mainly cultivated in South and East Asia but remains a minor grain legume in Sub-Sahara Africa (SSA). It has considerable potential for improving soil fertility and enhancing food security for smallholder farmers. Mungbean's short-duration growth cycle, symbiotic atmospheric nitrogen fixation, adaptation to hot and drought conditions, and low input requirements, make it suitable for rain-fed smallholder production systems of SSA. Its versatility as a short-duration crop makes it an ideal candidate for crop diversification, providing smallholder farmers with an additional income source and improving resilience against climate variability, which could contribute to promoting long-term agricultural sustainability. Having similar nutritional content to cowpea and dry beans, mungbean could perform better under semi-arid conditions due to its lower rate of flower and pod abscission. The legume is an important source of protein, carbohydrates, minerals, and vitamins and has lower phytic acid content than other legumes and staple cereals in SSA. Mungbean seeds can be eaten with cereals, processed to make dhals, sprouts, noodles, soups, desserts, and protein- and iron-rich supplements for children. This review highlights the agronomic traits of mungbean, focusing on its biological and ecological characteristics, its positive effects on soil health and the environment, as well as its nutritional and health benefits in SSA. Additionally, it discusses the key challenges to mungbean production in the region. The paper explores the use of genetic resources and genomic tools to enhance mungbean varieties' productivity and adaptability in SSA.

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## Introduction

*Vigna radiata* (known as mung beans or green gram) is an important legume crop in the semi-arid tropics of Asia, Africa, Southern Europe, and Central and Southern America. Worldwide, mungbean is cultivated on more than 6 million ha[1]. The species is a self-pollinated diploid (2n = 22), erect plant with branches carrying pods (8–15 seed grains) in clusters near the top of the plant (Fig. 1)[2], belonging to the *Papilionoideae* in the *Fabaceae*[3]. It belongs to the *Phaseoleae* tribe, which contains soybean (*Glycine max*) and cowpea (*Vigna unguiculata*)[4]. The genus *Vigna* includes more than 100 species in three subspecific taxa: *radiata* (green grams and golden grams including the cultivated mungbean), *sublobata*, and *glabra*[5]. Ninety percent of global production occurs in south, East, and Southeast Asia[6]. India represents the largest producer of mungbean worldwide followed by China and Myanmar. India's annual mungbean production is estimated to be around 3 M Mg, which represents over 50% of the total world production. Because of both the limited increase in mungbean production over the past years combined with limited access to high-quality seeds, current demand is high in India. Myanmar (83%), Tanzania (4%), Kenya (4%), Australia (3%), and Mozambique (2%) exports mungbean to India[7]. More than 50 improved mung bean varieties were released by India between 1985 and 2010, using extensive hybridization and selection, irradiation and selection. Most of these varieties are short duration (60–70 d), uniform maturity, high yield, and combined resistance to powdery mildew and/or mung bean yellow mosaic virus (MYMV). Few varieties have a maturity of 75 to 90 d and are intended for planting as winter or spring rice (*Oryza sativa* L.) fallows.

Mungbeans have low water and input requirements and wide adaptability into crop rotations, making it a potentially promising way to increase crop production under adverse soil, water, and climatic conditions. Their adaptation to stable

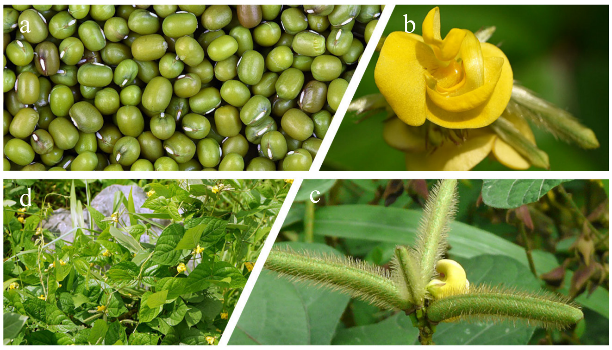

**Fig. 1** (a) Mungbean seeds, (b) flower, (c) developing pods, and (d) field crop[8].

performance in marginal environments has led to limited yield potential, which hampers its response to more favorable environments and improved cultural practices. They are mainly grown on small farms and in the tropical monsoon region, where they are used as a rainy-season crop on arid land or as a dry-season crop on wet land after the monsoon, using rice-based methods with residual moisture or supplementary irrigation. It is possible to plant an early-season crop before the monsoon in some areas where rainfall is sufficient. Mungbeans can produce reasonable yields in drought-prone areas such as SSA with as little as 650 mm of yearly precipitation. However, heavy rainfall leads to excessive vegetative growth and decreased pod formation and development. It is well-known that a range of biotic and abiotic constraints of natural origin, such as soil poverty, water scarcity, crop pests, diseases, and weeds, as well as inappropriate temperatures, reduce the productivity of food crops[9]. This results in less efficient use of inputs, lower agricultural production, and, ultimately, reduced food security in developing countries. However, there is growing concern that agricultural practices themselves, whether intensification systems, common in South Asia, or extensive systems, common in sub-Saharan Africa, are exacerbating the biotic and abiotic constraints on food production by having adverse effects on the environment[9]. In Sub-Saharan Africa, where reside the world's most vulnerable food production systems, recurrent droughts are projected to increase in frequency and intensity[10,11]. As a result of this, 60 to 90 million ha could be transformed into new arid and semi-arid areas in the following years, hence threatening future food security scenarios. In such a prospective scenario, a highly nutritious crop such as mungbean that can sustain high yield under mid to accentuated drought conditions, deserves special consideration for food security.

## Domestication and spread of mungbean

Genetic diversity data and archaeological studies revealed mungbean to be a native crop of India and the Indo-Burma region, where the early domestication and cultivation processes began 4,000–6,000 years ago. This initial assertion has been suggested by several authors, due to morphological diversity and the existence of weedy and wild varieties. From India and the Indo-Burma region, the domesticated mung bean has mainly spread through several routes in Southeast and East Asia. Later, the selection of species resulted in the introduction of cultivated types of mungbean by oriental emigrants or by traders to the Middle East, Africa, Latin and South America, and Australia[12]. Today, the modern mungbean varieties developed from several cycles of domestication and selection are currently found in Austronesia, Africa, and South and East Asia. In Africa, mungbean cultivation has been reported in at least 22 countries but remains a minor crop in the continent, except in Kenya where it represents a valuable source of protein, nutrients, and income for rural communities[13]. The available, limited mungbean literature for SSA highlights the importance of investigating the potential of mungbean production (Table 1).

*Vigna radiata* var. *sublobata* is believed to be the wild progenitor of mungbean, which is a popular legume grown for its edible seeds. This wild variety is found in various regions expanding from Central Asia, Central and East Africa, Madagascar, through Asia, New Guinea, to North and East Australia, where it thrives in diverse climates and soil conditions. Researchers are studying the genetic diversity of *Vigna radiata* var. *sublobata* to better understand its potential for improving mungbean cultivation and developing more resilient varieties for future agricultural practices.

Furthermore, the high protein, mineral, and vitamin contents of mungbean represent an opportunity for improving nutrition security in SSA. However, while mungbean has played an important role in improving soil fertility and sustaining the livelihood and nutritional security of smallholder farmers in other regions, it represents an understudied crop in SSA[14]. Mungbean is a tropical food legume that has an optimum temperature range for growth of 28–30 °C. It is extensively grown in the regions of South and East Asia that are prone to drought and high temperatures[7,15]. Global annual production of mungbean in 2017 was estimated to be approximately 2.7 M Mg, which represented about 3% of global pulse production that year[16]. Mungbean global production expected to be 3.2 M Mg by 2023 which represents a 15% increase due to an increased demand from the food industry[16].

Improved mungbean varieties reach maturity in 60 to 65 d[17] while traditional varieties mature in 65 to 90 d[1]. Mungbean varieties have determinate growth but flower and fruit over a

**Table 1.** Estimates of fixed N by mungbean in field trials.

| Country | N fixed (kg N ha$^{-1}$) | N method used* | Ref. |
|---|---|---|---|
| Pakistan | 55–86 | N balance | [19] |
| Pakistan | 35–83 | $^{15}$N isotope dilution | [20] |
| Philippines | 25–47 | $^{15}$N isotope dilution | [21] |
| Philippines | 21–85 | $^{15}$N isotope dilution | [22] |
| Philippines | 61–90 | $^{15}$N isotope dilution | [23] |
| Philippines | 21–85 | $^{15}$N isotope dilution | [24] |
| Thailand | 35–50 | $^{15}$N isotope dilution | [25] |
| Thailand | 10 | $^{15}$N isotope dilution | [26] |
| Australia | 20–83 | $^{15}$N natural abundance | [27] |
| Ethiopia | 8–25 | $^{15}$N natural abundance | [28] |
| Pakistan | 32–46 | $^{15}$N natural abundance | [29] |
| Pakistan | 41 | $^{15}$N natural abundance | [30] |
| Thailand | 64–66 | $^{15}$N natural abundance | [31] |
| Pakistan | 6–32 | Ureide | [32] |
| Pakistan | 17–47 | Ureide | [33] |
| Pakistan | 55 | Ureide | [30] |
| Pakistan | 19–47 | Ureide | [34] |
| Pakistan | 13–26 | Ureide | [35] |

* See Unkovich et al.[36] for description of techniques for measuring biological $N_2$ fixation.

period of several weeks (Fig. 1), which can result in multiple harvests[18].

## Production of mungbean

In SSA, mungbean grain yields exceeding 1.5 Mg·ha$^{-1}$ have been reported for improved varieties[37], while traditional varieties average about 0.5 Mg·ha$^{-1}$[13,38]. Mungbean is classified by the Food and Agriculture Organization (FAO), as a 'dry bean'. Few studies have been conducted to assess the adaptation, growth, and yield of introduced mungbean genotypes in Africa, but no prior article has reviewed the potential of mungbean in Sub-Saharan Africa to our knowledge.

While production of major legume crops such as groundnut, cowpea, and common beans has seen an important increase in Sub-Saharan Africa in the last 20 years (Fig. 2), mungbean production has remained low and stable[17]. One of the reasons behind this phenomenon could be explained by the low adoption of superior mungbean lines by farmers in SSA. In major mungbean-producing countries in this region, recently reported average yields fluctuated between 0.2 to 0.5 Mg·ha$^{-1}$[39] while potential yields of 2.0 Mg·ha$^{-1}$ have been reported in trials[40]. Although the use of improved mungbean lines developed by the World Vegetable Centre have shown promising results in Asia, African farmers still use traditional varieties that are low yielding, small-seeded, susceptible to pests and diseases, and pod-shattering[39]. A participatory selection study of mungbean genotypes conducted in Uganda has revealed farmers' preferences for high-yielding and large-seeded genotypes compared to landraces[37]. These findings suggest that breeding efforts to enhance mungbean productivity need to focus on farmers' needs.

## Agronomic performance of mungbean

Mungbean is usually grown on marginal lands under rainfed conditions. It is well adapted to arid and semiarid conditions and is suitable for planting at a range of altitudes, temperatures, and soil types. However, it grows best in subtropical regions with average annual rainfall in the range of 600–900 mm and at altitudes not exceeding 2,000 m on well-drained loams or sandy loam soils[13]. Mungbean is well-suited to many cropping systems due to its ability to improve soil fertility and sustain productivity of subsequent crops in subsistence agriculture. Multiple factors contribute to mungbean's drought-tolerance such as rapid seedling growth rate (significantly positive correlation ($p < 0.05$) with drought-tolerance, deep root system with extensive proliferation, and efficient stomatal conductance together with better photosynthetic capacity under water stress[42]. Despite being drought-tolerant, prolonged drought can lead to reduced pod formation, grain yield, and higher abortion rates. Mungbean also has a lower abortion of flowers or pods (14%–37%) compared to 43%–81%, 48%–76%, and 70%–88% in soybean, common bean, and cowpea, respectively. Addressing these challenges through mungbean varieties can improve drought tolerance and productivity, making mungbean a valuable crop for sustainable agricultural systems in SSA.

Mungbean is an environmentally sustainable food legume, maintaining or enhancing soil fertility and reducing inorganic nitrogen needs. However, with the prevalence of poor soils in SSA, application of fertilizers could help in improving mungbean growth and yield under low soil fertility conditions. Diatta et al.[43] found that utilizing organic amendments could serve as a viable substitute for expensive and inaccessible inorganic fertilizers to enhance mungbean output in low-input agricultural systems. Like other legume crops, seed inoculation of mungbean with an appropriate stain of *Rhizobium* ssp. can result in a 10%–12% increase in productivity[18]. In addition, soils in SSA are characterized by low content of essential nutrients, particularly phosphorus, which is crucial for crop growth. Phosphorus deficiency affects root development, seed formation, and yields, which directly affect crop yields. For mungbean, adequate phosphorus availability is vital for root proliferation, nodulation, and effective nitrogen fixation, all of which enhance its productivity. The inoculation of mungbean with arbuscular mycorrhizal fungi has been shown to improve its adaptation to low-phosphorus environments, enhancing the absorption of phosphorus from the soil[44]. Arbuscular mycorrhizal fungi can improve the uptake of slow diffusing soil nutrients like phosphorus and micronutrients such as zinc. This symbiotic relationship between mungbean, *Rhizobium* ssp. and

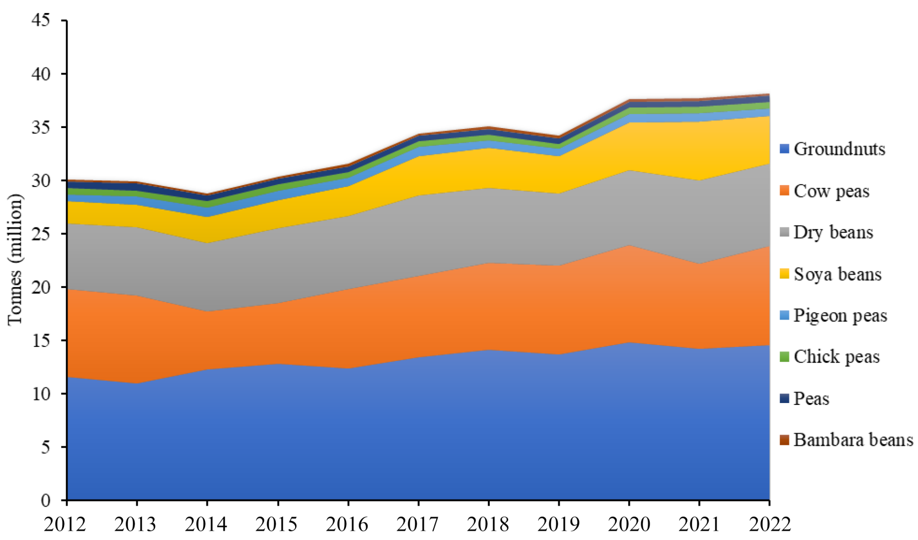


**Fig. 2** Annual production of major pulse crops in Sub-Saharan Africa during the period between 2012 and 2022 (M Mg). *Source*: FAOSTAT[41].

arbuscular mycorrhizal fungi can promote and sustain mungbean productivity, even under drought conditions.

Additionally, the ability of mungbean to fix atmospheric nitrogen (Table 1) and its adaptability to diverse climatic conditions make it an optimal crop for integration into rotational cropping systems in SSA. Mungbean, when intercropped with cereals such as maize, millet, or rice, improves soil fertility by increasing soil nitrogen levels, which could benefit to succeeding crops and diminishing the need for synthetic fertilizers. Zang et al.[45] noted that 10% of fixed nitrogen can be transferred to companion and subsequent crops, while the larger percentage remained in the soil. This finding suggests that mungbean rhizodeposition may enhance nitrogen availability in the soil for following crops. Thomas et al.[46] indicated that crop rotation, incorporating legumes such as mungbean, enhances the profitability and sustainability of crop production in contrast to continuous winter cereal cropping by optimizing water utilization, nitrogen efficiency, and market prices, while mitigating detrimental impacts of plant diseases. In addition, mungbean can be also sown post-harvest of a grain crop, utilizing remaining soil moisture for rapid growth and nutritional replenishment. The integration of short-duration summer mungbean, with a growth period of 60 d, after harvesting potato (*Solanum tuberosum* L.) and wheat (*Triticum aestivum* L.) in the Indo-Gangetic Plains of India resulted in nitrogen addition and economic returns[47].

Intercropping systems are common agronomic techniques extensively practiced by subsistence farmers in Sub-Saharan Africa. Intercropping cereals with legume crops such as mungbean could increase the productivity of the land and minimize the risk of crop failure[48]. In Senegal, Trail et al.[49] intercropped pearl millet [*Pennisetum glaucum* (L.) R. Br.] with mungbean (1:1 row ratio; 1 m × 1 m for millet and 1 m × 0.5 m for mungbean) and noted a 36% increase in millet grain yield compared to monocropped millet spaced 1 m × 1 m for a planting density of 10,000 hill per hectare. Naresh et al.[50] reported that a 1:1 row ratio of pearl millet and mungbean produced the maximum millet grain yield of 1,086 $kg \cdot ha^{-1}$ among all intercropping treatments. Ghilotia et al.[51], however, found that millet yielded more (1,568.40 $kg \cdot ha^{-1}$) when grown alone compared to intercropping with mungbean. Shaker-Koohi et al.[52] intercropped mungbean with sorghum in a field experiment conducted in Iran and reported that intercropping treatments had higher intercropping advantage (3.22), relative yield totals (1.36) and land equivalent ratio (> 1) compared to monocropping.

From an environmental standpoint, mungbean can improve crop yields and water use efficiency in Sub-Saharan Africa through reduction of soil surface temperature and water evaporation and addition of nutrients and organic matter to soil when grown as green manure and/or cover crops. Among others, characteristics such as early establishment, high seedling vigor, and $N_2$ fixation efficiency, short growing season with significant biomass production, favorable nitrogen to carbon balance, and easy incorporation and quick degradation into the soil, make mungbean a suitable crop for soil improvement in Sub-Saharan Africa. Using mungbean as cover crop in semi-arid watersheds has resulted in reduced soil erosion through a decrease in runoff (28%) and sediment (30%) losses compared to bare soil[53]. Using mungbean as a cover crop may also reduce weed infestation of the companion crop[54]. Weed density and fresh weed biomass were 34% and 54% lower, respectively, under maize-millet intercropping (6:10 row ratio) compared to maize monocropping in Pakistan[55].

Moreover, mungbean has been used as an environmentally sound and sustainable approach for managing insects in cropping systems. A study conducted by Lu et al.[56] to assess the potential of mungbean as a trap crop revealed a 50% decrease in mirid bug [*Apolygus lucorum* (Meyer-Dür) (Heteroptera: Miridae)] population densities compared to cotton fields without mungbean plants (36 individuals per 100 plants). Similar findings were also reported by Geng et al.[57] who observed not only significantly higher number of adults and first instar nymphs of *A. lucorum* but also longer adult longevity and fecundity on mungbean compared to cotton plants ($p < 0.05$). To understand the migration of *A. lucorum* adults between neighboring cotton and mungbean fields, Wang et al.[58] developed a DNA-based polymerase chain reaction (PCR) approach. Findings from this study revealed a detection of cotton DNA in the guts of *A. lucorum* collected from mungbean plots evidencing the migration *A. lucorum* from cotton to mungbean plots. Results from these studies could help in developing mungbean-based trap-cropping strategies for controlling *A. lucorum* on agricultural crops.

Mungbean is also highly efficient in the use of nutrients, especially nitrogen, allowing smallholder farmers in Sub-Saharan Africa to achieve acceptable grain yields on marginal lands and under low fertility management. While mungbean crops have been successfully grown in SSA under low-technology schemes to date, ensuring a timely and efficient nitrogen availability to the crop will represent a key management decision to increase grain yields in a region where little to nothing can be done regarding water availability to the crop.

## Nutritional value of mungbean

The high nutritional value of mungbean makes it a good source of protein, minerals, and vitamins to smallholder households. Mungbean has a high protein content, complementing to deficiencies of cereal-based diets in SSA[17]. Mung bean is an important source of protein in South and Southeast Asian countries where it is usually known as the 'poor man's meat'. Studies determining the proximate composition of mungbean report a wide variation in protein values (15% to 33%)[59,60]. Mungbean has a comparable protein content to chickpea, kidney bean, cowpea, groundnut, and pigeon pea (Table 2)[61]. Mungbean is also a rich source of amino acids like arginine, isoleucine, leucine, lysine, phenylalanine, valine, aspartic acid, glutamic acid, and serine (Table 3)[60]. The relatively high protein and lysine content, added to the low content of methionine in mungbean makes it a good complement for cereals with high carbohydrate, low lysine, and high methionine concentrations[62]. Although mungbean is an important source of protein, its protein nutritional quality is limited by low concentrations of sulfur-containing amino acids such as methionine and cysteine with 0.29 g and 0.21g in 100 g of a raw edible portion[38].

Anti-nutritional compounds reduce the nutritive value of food due to limited digestibility, bioavailability, and bioconversion of nutrients. Anti-nutritional compounds reported in mungbean include tannins, phytic acid, hemagglutinins, polyphenols, trypsin inhibitors, and proteinase inhibitors[60]. However, the reported amount of anti-nutritional components in mungbean like trypsin, hemagglutination, saponins, pythic acid, and insoluble dietary fiber, have been relatively lower

**Table 2.** Absolute nutritional content (in g or mg) of major crop legumes grown in Africa and Asia*.

| Crop | Protein (g) | Oil (g) | Calcium (mg) | Iron (mg) | Zinc (mg) | Vitamin A (mcg-RAE) | Vitamin C (mg) | Folate (mcg) |
|---|---|---|---|---|---|---|---|---|
| Mungbean | 26 | 1 | 145 | 7 | 3 | 7 | 5 | 687 |
| Mungbean sprout | 32 | 2 | 135 | 9 | 4 | 10 | 138 | 635 |
| Chickpea | 22 | 7 | 119 | 7 | 4 | 3 | 5 | 630 |
| Cowpea | 27 | 2 | 96 | 11 | 7 | 2 | 2 | 718 |
| Groundnut | 28 | 53 | 98 | 5 | 3 | 0 | 0 | 257 |
| Kidney bean | 27 | 1 | 162 | 9 | 3 | 0 | 5 | 446 |
| Pigeon pea | 21 | 5 | 123 | 5 | 3 | 9 | 114 | 507 |
| Soybean | 40 | 22 | 303 | 17 | 5 | 1 | 7 | 410 |
| Soybean, green | 40 | 21 | 606 | 11 | 3 | 28 | 89 | 508 |

* Value per 100 g raw product (dry weight basis). Source: (USDA, 2010).

**Table 3.** Amino acid composition of mung bean.

| Amino acid (g/16 g of nitrogen) | Average* | Minimum | Maximum |
|---|---|---|---|
| Alanine | 4.1 | 3.6 | 4.5 |
| Arginine | 5.8 | 4.5 | 6.7 |
| Aspartic acid | 13 | 12 | 15.1 |
| Cysteic acid | 13.5 | 13.5 | 13.5 |
| Glutamic acid | 18.3 | 13.6 | 21.7 |
| Glycine | 3.6 | 3.2 | 4.3 |
| Histidine | 3.2 | 2.4 | 5.6 |
| Isoleucine | 4.3 | 3.6 | 5.4 |
| Leucine | 7.6 | 6.9 | 8.7 |
| Lysine | 6.5 | 4.1 | 8.1 |
| Methionine | 1.2 | 0.5 | 1.9 |
| Phenylalanine | 5.4 | 4.6 | 6.2 |
| Proline | 4.5 | 3.7 | 5.6 |
| Serine | 4.9 | 4 | 5.8 |
| Threonine | 3.2 | 2.7 | 4 |
| Tryptophan | 1.2 | 0.5 | 3.4 |
| Tyrosine | 2.7 | 2.2 | 3.3 |
| Valine | 5.1 | 4.1 | 6.4 |

* Mean value of all collected data[60].

compared to other legume crops such as soybean and cowpea[63]. Variation in the amounts of anti-nutritional components in mungbean can likely be explained by differences in genetic variation among cultivars[64]. Processing techniques to decrease the concentration of anti-nutritional factors in mungbean include breeding research, agronomic techniques, and food preparation processes such as sprouting, dehulling, soaking, germination, boiling, and cooking[59]. Preparing mungbean seeds with vegetables has been shown to lower the concentrations of anti-nutritional factors such as trypsin, hemagglutination activity, saponin, phytic acid, and insoluble fiber[65]. Split seeds consumed with rice are beneficial for children and elderly people.

Additionally, mungbean seeds are an important source of carbohydrates (59%–65%), minerals (particularly iron), vitamins, and amino acids in human diets[60] (Table 2). Minerals present in mungbean seeds include iron, calcium, phosphorous, magnesium, and potassium[66]. Mungbean seeds contain 1%–1.5% fat, 3.5%–4.5% fiber, and 4.5%–5.5% ash[67]. Adding to its highly desirable nutritive composition, mungbean is also considered valuable for good health and human development because of the high digestibility of its protein and carbohydrates[68]. The digestibility value of mungbean (67%–72%) is comparable to chickpea (65%–79%), pigeon pea (60%–74%), soybean (63%–72%), and urd bean (56%–63%)[69].

## Food, feed, and non-food uses of mungbean

Mungbean is an important food and livestock feed legume crop in tropical and subtropical regions and is extensively consumed for its protein-rich grains (Table 4)[70]. Mungbean grains are typically consumed as boiled or cooked with vegetables or meat[17]. It can also be used to make sprouts, soups, noodles, desserts, and several other food products[71]. In East Africa, mungbean is commonly consumed as a vegetable and processed seed. In Kenya and Tanzania, mungbean green pods and immature seeds are consumed with a popular thick maize porridge called ugali[67]. Mature seeds of mungbean are also commonly boiled together with maize, sorghum, and other cereals or fried with meat or vegetables in Kenya[67]. In Uganda, mungbean represents an important food product and source of income for smallholder farmers[39]. Consumption of cooked mungbean seeds in sauces and as a side dish is common in Ethiopia and Malawi, respectively[13]. In West Africa, on the other side, recent efforts to improve food security and soil fertility through crop diversification have resulted in the introduction and development of mungbean[72]. In Nigeria, mungbean is consumed as sprouts in salad or processed into biscuits[73]. Mungbean seeds and leaves are boiled and consumed with rice or millet in Senegal[74]. A study on dietary diversity of women and children conducted in Senegal revealed that the inclusion of mungbean into the Senegalese diet could be a major addition to the limited legume crops and supplement to cereal-based diets[75].

In India, mungbean is consumed as whole or split seeds which are transformed into a thick soup called 'dhal'[76]. In China, food products made of mungbean include soup, porridge of mungbean and rice, sprouts, starch noodles, and cakes, while cold jellies and cakes represent the popular food products in Thailand[67]. After removing the seed coat, mungbean seeds may also be ground into flour. Mungbean flour can be further transformed into various products such as noodles, bread, biscuits, and vegetable cheese, used to fortify wheat flour, or to formulate high-protein food supplements for children (Table 4)[67]. Imtiaz et al.[77] revealed that 44% wheat flour with 36% mungbean flour or 56% wheat flour with 24% mungbean flour combined with 10% skim milk powder and 10% sugar in both cases can be used as weaning food. However, work on the effects of processing methods on protein concentration has shown that processing could improve the nutrient composition of mungbean flours[78].

Mungbean may provide opportunities for improving the health of rural populations in Sub Saharan Africa (Table 4). The relatively high concentration of proteins, amino acids, oligosaccharides, and polyphenols in mungbean make it suitable for antioxidant, antimicrobial, anti-inflammatory, and anti-tumor use[79]. Mungbean soup has been successfully used to increase total antioxidant capacity and glutathione levels and to subsequently alleviate heat stress in rats[80]. Results from this study demonstrate the potential of mungbean soup in reducing the risk of heat stress in humans.

Mungbean crop residues are a good quality forage for livestock, particularly as a high-protein supplement to produce

**Table 4.** Food, feed, and non-food uses of mungbean.

| Category | Uses | Description |
|---|---|---|
| Food | Whole seeds | Mungbean seeds are commonly boiled and consumed as a side dish or with cereals such as rice or millet. |
| | Split seeds (Dhal) | In South Asia, mungbean seeds are split to make dhal, a thick soup served with rice or bread. |
| | Sprouts | Mungbean seeds are sprouted and eaten in salads, sandwiches, or stir-fried dishes, rich in vitamins and minerals. |
| | Noodles and soups | Mungbean flour is used to make glass noodles and soups in Asian cuisines, particularly in China and Southeast Asia. |
| | Desserts and sweets | Mungbean is used in making traditional sweets like cakes and jellies, especially in Asian countries. |
| | Flour | Mungbean seeds are ground into flour, used in baking, or mixed with wheat flour to increase the protein content of baked products. |
| | Baby food supplements | Mungbean flour, rich in protein and iron, is used as a supplement in baby food products to improve nutritional quality. |
| | Fermented foods | Mungbean is used in the fermentation process to create food products like tempeh, which are rich in probiotics and proteins. |
| Feed | Livestock fodder | Mungbean residues (leaves and stems) are fed to livestock, providing a high-protein feed that supports meat and milk production. |
| | Green manure | Mungbean is grown as a cover crop, and its biomass is incorporated into the soil as green manure, enriching the soil with organic matter and nutrients. |
| Non-food | Trap crop for pest management | Mungbean is used as a trap crop in integrated pest management systems to reduce pest populations on cash crops like cotton. |
| | Soil improvement (nitrogen fixation) | As a legume, mungbean fixes atmospheric nitrogen, enhancing soil fertility for subsequent crops in crop rotation systems. |
| | Erosion control | When used as a cover crop, mungbean helps reduce soil erosion by stabilizing the soil surface and reducing water runoff. |
| | Industrial applications (starch production) | Mungbean starch is extracted and used in the production of biodegradable plastics, cosmetics, and other industrial applications. |

high-quality meat and milk (Table 4). Sherasia et al.[81] reported that fresh forage mungbean contains 13%–21% of protein on a dry matter basis and mungbean straw has 9%–12% protein content. Forage yields of non-fertilized mungbean plants averaged 0.64 t·ha$^{-1}$ while 1.4 t·ha$^{-1}$ was recorded under fertilized conditions[81]. However, aboveground samples of mungbean for forage yielded 2.9 t·ha$^{-1}$ in central Oklahoma, USA[82]. Because mungbean matures quickly, it offers forage while other legume crops such as cowpea or velvet bean are still maturing[83].

## Major constraints to mungbean production

The productivity of mungbean, widely grown over a range of environments is constrained by abiotic and biotic stresses[1]. Among abiotic stresses, drought and flooding are two of the major constraints to mungbean production in SSA. High rainfall variability has led to a reduction in suitable lands for bean production and a subsequent decrease in agricultural production[14]. Drought and flooding stresses have been reported to limit growth and yield of mungbean[84]. To understand the effects of water stress on phenological and agronomic traits of mungbean, Lalinia et al.[85] applied four irrigation regimes (no water stress, drought stress at the flowering, during pod and seed formation) to five mungbean cultivars in Iran. They found that drought stress manifested in mungbean through decreased plant height, 100-grain weight, number of grains per pod, number of pods per plant, days to flowering, and physiological maturity. This decrease in mungbean growth and yield components when grown under drought stress conditions could be explained by inefficient stomatal regulation and low photosynthetic capacity under limited soil moisture stress conditions[7]. An excess of water can be detrimental to mungbean productivity. Working with five mungbean genotypes in Bangladesh, Amin et al.[84] found that a 4-d flooding imposed at 24 d after emergence induced a decrease in total dry matter and seed yield through a reduction in the pods per plant and the seed size of all genotypes. The decrease in mungbean productivity could be explained by the reduction in leaf photosynthesis, stomatal closure, and growth inhibition[42].

Fewer pest and disease problems have been reported in mungbean compared to other legumes such as soybean, common bean, and cowpea resulting in more stable yields[17]. Yield loss of mungbean can be caused by field pests such as whitefly, *Bemisia tabaci* (Genn), leaf hopper, *Empoasca kerri* (Pruthi), black aphid, *Aphis craccivora* (Koch), Bihar hairy caterpillar, *Diacrisia obliqua* (Wlk.), galerucid beetle, *Madurasia obscurella* (Jacoby), stem fly, *Ophiomyia (Melanagromyza) phaseoli* (Tryon), lycaenid borer, *Euchrysops cnezus* (Fabr), and spotted caterpillar, *Maruca testulalis* (Geyer)[86]. Integrated management strategies of mungbean pests include resistant cultivars, clean seeds, cultural practices, and biological and chemical control approaches[87]. The major viral disease that constrains mungbean production is Mungbean Yellow Mosaic Virus (MYMV)[88–90]. MYMV, favored by maximum temperature and humidity[91] and whitefly population[92], is caused by *Begomovirus* species transmitted by whitefly (*Bemisia tabaci* Gennadius)[93]. However, the incidence of MYMV in mungbean has not been reported in SSA.

Additional major diseases of mungbean reported in major producing regions include powdery mildew [*Podosphaera fusca* (Fr.) U. Braun & Shishkoff], anthracnose [*Colletotrichum acutatum* (J.H. Simmonds)], cercospora leaf spots [*Cercospora canescens* Ellis & G. Martin], *Erysiphe polygoni* (Vaňha) Weltzien), *C. truncatum* (Schwein.) Andrus & Moore, *C. gloeosporioides* (Penz.) Penz. & Sacc), and wet root rot [*Rhizoctonia solani* (Kuhn)][88–90]. Options to reduce the impacts of mungbean pathogens involve integrated disease management such as combinations of insecticides, fungicides, and bio-formulation as a seed treatment. Dubey & Birendra[88] revealed that mungbean seeds treated with a combination of thiamethoxam (insecticide) at 4 g·kg$^{-1}$, carboxin (fungicide) at 2 g·kg$^{-1}$ and Pusa 5SD (*Trichoderma virens*) at 4 g·kg$^{-1}$ recorded a low incidence of Cercospora leaf spots, MYMV, and wet root rot. Although these diseases have not been reported as major threat to mungbean in SSA, expansion of mungbean beyond Asia will need the development of high-yielding and disease-resistant mungbean varieties.

Lack of policy and research attention can also constrain the productivity of mungbean in Sub Saharan Africa[94]. Increases in mungbean productivity is often limited by an insufficient supply of suitable cultivars and high-quality seeds coupled with the lack of training programs on mungbean potential benefits for agricultural productivity, soil, and human health[14,17]. As a result, adaptive and strategic research associated with the development of a strong network and financial support will be helpful to promote mungbean from being a marginal crop to become one of the major grain legume crops in SSA, as was the case in Asia[38].

## Potential for mungbean improvement

For increased mungbean adoption in Sub-Saharan Africa, agronomic practices for improving mungbean yields could be optimization of row spacing and plant density to increase mungbean production through increased cumulative intercepted radiation and increased water use efficiency for specific environments. Diatta et al.[18] reported that inoculation of mungbean with *Bradyrhizobium* inoculum (group I) increased the number of pods per plant, number of seeds per plant, and seed yield by 15%, 18%, and 14%, respectively over uninoculated mungbean. HanumanthaRao et al.[1] & Trail et al.[49] suggested that surface organic mulch could also be used to alleviate heat stress of mungbean under semi-arid conditions through a decrease in soil temperature and reduced loss of soil water.

Promotion and utilization of mungbean in agriculture in Sub-Saharan Africa will require enhancement of production and nutritional value through breeding and better management practices under environmental and economic constraints[1,60]. To fully utilize mungbean to increase agricultural resiliency in SSA, the changing climatic conditions will need concomitant screening of existing varieties and genetic improvements to develop high-yielding varieties with short growing season, disease-resistant, and tolerant to waterlogging and salinity[7]. In this regard, efforts to develop improved varieties of mungbean with synchronous maturity, short growing season (60–75 d), higher yields (> 2 $Mg \cdot ha^{-1}$), and better nutritional composition were recently initiated in South Asia[15]. Despite these efforts, limited data on the genome sequence for *Vigna* species in developing countries resulted in limited advancement of molecular breeding research in these regions, particularly in SSA[6]. Participatory selection of high yielding and nutrient-dense cultivars should be continued in Eastern Africa but also encouraged in other Sub-Saharan regions[37].

Because of the genetic variability of mineral composition in mungbean varieties, biofortification has a great potential for enhancing micronutrient concentrations, and thus its nutritional quality[15,60]. For example, interspecific breeding of mungbean with black gram [*V. mungo* (L.) Hepper], a close relative of mungbean could be used to increase the low concentration of the essential amino acid methionine[67]. The establishment of seed production and distribution systems and creation of agronomic and market opportunities will be necessary for smallholder farmers[17]. The development of training programs in mungbean production such as the organization of field days and demonstration trials need to be promoted to sustain food production in SSA[17]. These training programs should also take into account the diversity of agro-ecological conditions and socio-economic factors in SSA[48]. Finally, expansion of mungbean in SSA may also require adequate financial support from national research institutes, international organizations, and the private sector to sustain and capitalize research findings on best agronomic practices, breeding efforts, and adaptation strategies of mungbean to current agriculture systems in SSA.

## Prospects for Sub-Saharan Africa

The projected increase in climate variability, as well as increased frequency and intensity of extreme weather events is expected to have a negative impact on agricultural production worldwide. Rainfall variability and persistent droughts and floods are reported to contribute to decreased crop yields[95], fluctuation and volatility of food prices[96], negative impacts on livelihoods[10], and increased poverty and malnutrition[97]. Development of adaptation strategies and mitigation efforts that would anticipate effective responses and interventions will be important in Sub-Saharan Africa where the most vulnerable populations are located[11]. Such strategies include improvement of agricultural management practices[98] and sustainable intensification[99], use of high-yielding and drought and heat-resistant crop genotypes[100], intensified use of technology inputs[101], natural resource stewardship[102], and development of policy and community programs[10].

## Conclusions

This paper highlights the promising yet largely unexploited potential of mungbean for diversifying and increasing crop productivity, promoting sustainable adaptation strategies, and reducing food insecurity and poverty in Sub-Saharan Africa. Mungbean's N fixation potential, agronomic advantages, and nutritional potential makes it a valuable crop for meeting the ever-increasing global need for food and nutritional security. Broad production and consumption of mungbean in SSA should be encouraged by the active promotion of both good agronomic practices and information about the nutritional value of mungbean for human health.

Nutritional and agronomic benefits should be also given research and development attention supported by a multidisciplinary approach. Existing germplasms need to be extensively screened to find the best varieties for varied environments in SSA and acceptability for local cuisine. In this regard, 550 mungbean varieties from USDA and AVRDC are being screened for the best agronomic and nutritional traits in Senegal. In addition, variety screening is relatively inexpensive and provides immediate resources for growers, thereby promoting adoption.

Upon identifying the suite of biotic and abiotic constraints, it will be important to set priorities for breeding programs' focusing on incorporating disease resistance into the varieties identified as best adapted to the physical environment. Thus, innovative mungbean breeding and agronomic technologies can be utilized to develop new varieties with superior agronomic, adaptive, and nutritional traits suitable for current cropping systems in SSA. Increased production and adoption of mungbean can support sustainable production and improve the livelihoods of smallholder farmers in SSA.

## Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Diatta AA, Abaye O, Thomason WE; data collection: Diatta AA, Battaglia ML, Leme JFDC; analysis and interpretation of results: Diatta AA; Battaglia ML, Seleiman M, Babur E; draft manuscript preparation: Diatta AA, Abaye O, Wade ET. All authors reviewed the results and approved the final version of the manuscript.

## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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